A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response

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A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response

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Abstract: Demand response is increasingly attracting policy attention. It involves changing electricity demand at different times based on grid conditions, which could help to integrate variable renewable generation and new electric loads associated with decarbonisation. Residential consumers could offer a substantial new source of demand-side flexibility. However, while there is considerable evidence that at least some residential users engage with at least some forms of demand response, there is also considerable variation in user engagement. Better understanding this variation could help to predict demand response potential, and to engage and protect consumers participating in demand response. Based on a systematic review of international demand response trials, programmes and surveys, we identify motivations for participation, and barriers and enablers to engagement including familiarity and trust, perceived risk and control, complexity and effort, and consumer characteristics and routines. We then discuss how these factors relate to the features of different demand response products and services. While the complexity of the evidence makes it difficult to draw unequivocal conclusions, the findings of this review could contribute to guide early efforts to deploy residential demand response more widely.

Keywords: demand response; demand-side management; flexibility; residential; consumer engagement

1. Introduction

Demand response is increasingly attracting policy attention as a resource to increase the flexibility of electricity systems (COWI, 2016; National Infrastructure Commission, 2016; Grunewald and Diakonova, 2018; Srivastava, Van Passel and Laes, 2018) as well as reduce the carbon intensity of electricity supply (Vine, 2008; Smith and Brown, 2015). Electricity systems require supply and demand to be balanced within tight limits in real time, which has traditionally been achieved mainly by sizing generation, reserves, and transmission and distribution network capacity to meet predicted demand (Strbac, 2008). This will become more challenging if electric heating and transport increase peak electricity demand, and electricity systems include much higher penetrations of less flexible generation (Strbac, 2008; Pudjianto *et al.*, 2013; Kroposki, 2017).

Demand response describes flexible electricity demand that can be increased or decreased at specific times, for example to make use of high wind generation or reduce demand peaks. This may help to integrate variable renewable generation and new electric loads cost effectively. Recent inputs to policy making have reinforced the message that enhancing system flexibility is a key factor in minimising the costs of integrating variable renewable sources of electricity (Aurora, 2018; Vivid Economics and Imperial College London, 2019). While commercial and industrial consumers currently contribute more to demand response in many countries, including the UK (National Infrastructure Commission, 2016), residential consumers theoretically represent a large additional source of flexibility (Gils, 2014) with potentially considerable value in decarbonised energy systems (OVO Energy and Imperial College London, 2018).

Accessing demand side flexibility could require residential electricity consumers to engage with demand response programmes. EPRI (2012) characterise engagement with demand response as participation (being enrolled in demand response), performance (responding in the desired way) and persistence of effects over time, elements summarized in Fig. 1. Assessments of demand response *potential* reveal that it offers greater flexibility over shorter time frames, and indicate which types of demand response or electrical loads offer greatest potential for integrating variable renewables (Cappers *et al.*, 2012; Müller and Möst, 2018). The *performance* of demand response trials and programmes considering enrolment, response and persistence was reviewed by Parrish, Gross and Heptonstall (2019) in order to compare the results with assumptions included in studies modelling residential demand response. There is considerable evidence that at least some residential users engage with at least some forms of demand response. However, there is also considerable variation in user engagement across different demand response programmes and trials, and across different users within the same trials or programmes (EPRI, 2011; Carmichael *et al.*, 2014; Parrish, Gross and Heptonstall, 2019). This paper therefore builds on previous work through a systematic review of demand response trials, programmes and surveys that addresses the question: what are the key factors affecting residential user engagement with demand response?

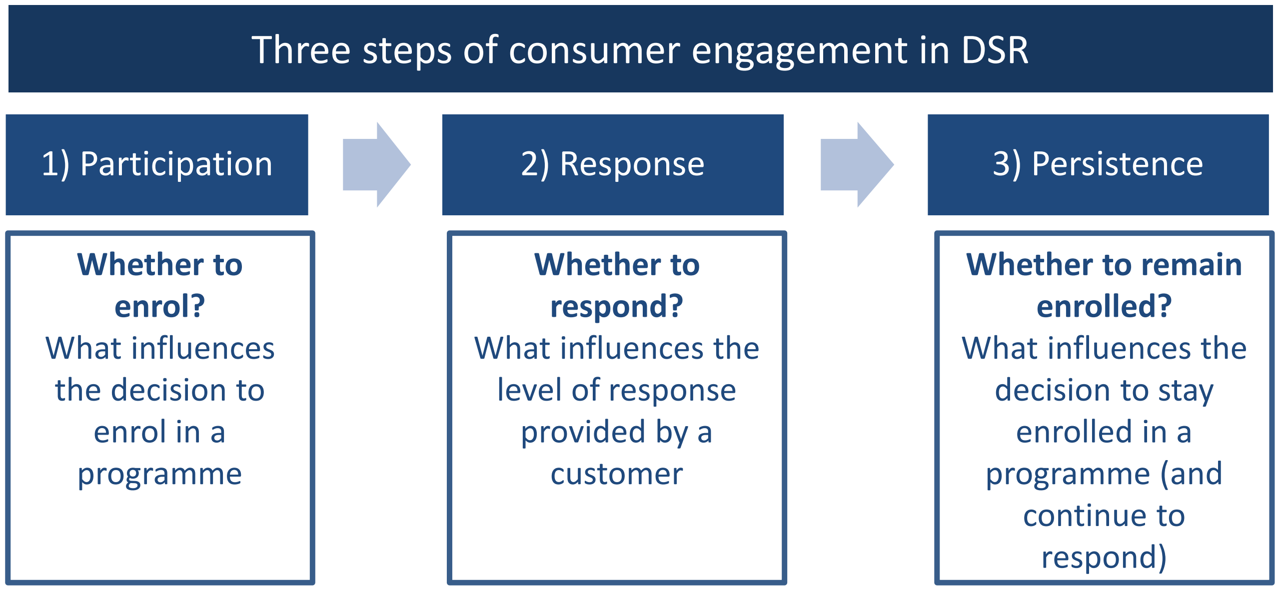

Fig. 1: Stages of consumer engagement in Demand Response (EPRI, 2012)

Better understanding the factors that affect residential user engagement with demand response is relevant to policy for several reasons. It could allow demand response potential to be more accurately predicted (US DOE, 2016), or reduce marketing costs by target marketing to users who are likely to offer the greatest performance (EPRI, 2012). It could help to increase user engagement with demand response (US DOE, 2014), and also to protect users by better informing them of whether they are likely to benefit from different demand response products and services (Steel, 2014). To better understand residential user engagement with demand response, this paper presents the findings of the systematic review under the themes of consumer motivations, barriers and enablers, and user routines and characteristics. It goes on to discuss how these findings relate to the characteristics of different demand response products and services, and suggests policy implications for delivering residential demand response.

The remainder of the paper is structured as follows: Section 2 reviews key concepts in demand response, including a range of demand response products and services, to provide the background for the findings and discussion; Section 3 describes the research design, a systematic review; Section 4 presents our thematic findings; Section 5 discusses the implications of these findings for user engagement with different forms of demand response; Section 6 concludes and suggests policy implications.

2. Background

This section provides an introduction to the principles of demand response and a range of demand response products and services. This provides background for less familiar readers, and the main characteristics that differentiate different types of demand response form part of the discussion in Section 5.

The premise for flexible electricity demand by residential consumers is the idea that consumers use electricity to provide energy services, and that electricity use and the provision of energy services can sometimes be temporally separated. This suggests two categories of theoretically flexible loads. The first category comprises loads with thermal inertia: space and water heating, air conditioning and refrigeration. Because it takes time for temperature to rise or fall, it may be possible to change the timing of electricity demand while maintaining energy service provision. This can be enhanced by increasing thermal insulation or including additional thermal storage, such as hot water tanks, chilled water or ice storage. The second category comprises loads where electricity demand and demand for energy services are separated in time. This category includes the so-called 'wet' goods or appliances: washing machines, dishwashers and tumble dryers. This theoretical perspective suggests that other energy services, such as lighting, cooking and entertainment, will be less flexible because their involvement in demand response implies users changing their demand for these energy services.

Demand response typically relies on economic incentives to encourage consumers to shift demand. These can take the form of time varying pricing or rebates for changes in demand compared to a predicted baseline level; consequently, demand response is commonly classified as either price based or incentive based. However, some schemes do not include any economic incentive and aim to change demand based on information provision alone. Demand response may involve technologies to provide additional information to participants, for example on current pricing levels, and may rely on manual behaviour change or be facilitated by appliance automation or direct load control. Finally, types of demand response vary by the timing of demand response signals, which may vary daily or target occasional events a few times per year. They may also be classified as *static* or *dynamic* according to whether or not pricing or other signals follow a predetermined schedule.

The classifications and the main types of demand response discussed in this paper are outlined in Fig. 2 and Table 1

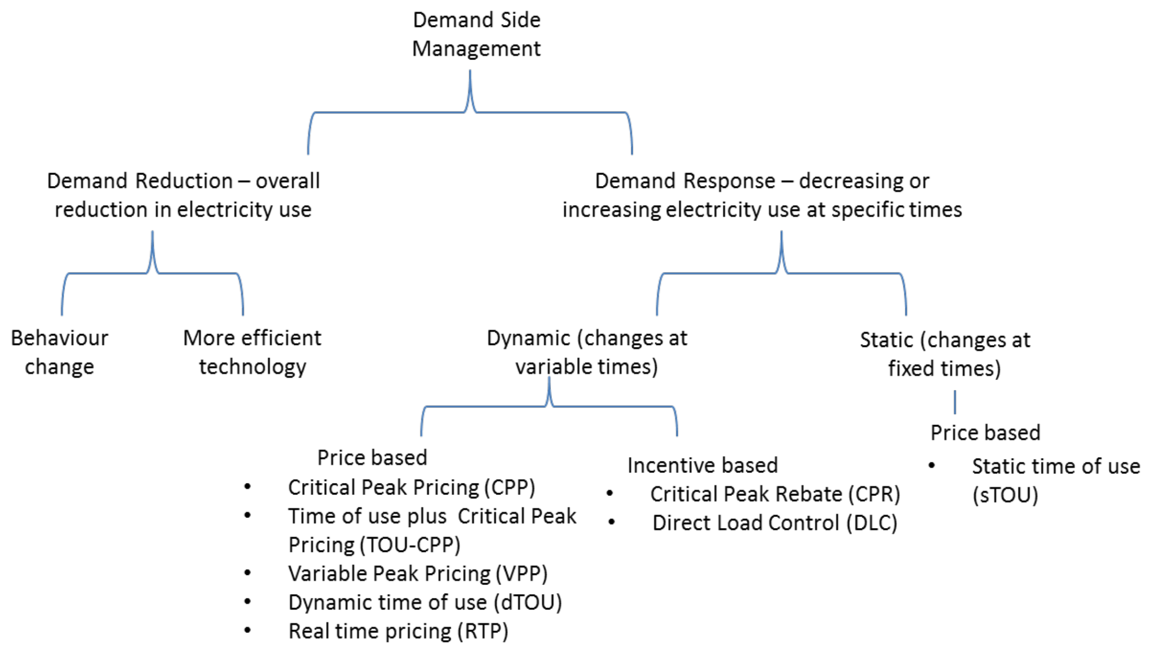

Fig. 2: Classifications of demand reduction and demand response (Parrish, Gross and Heptonstall, 2019).

Price based schemes	Description
sTOU (static time-of-use)	Prices vary by time of day between fixed price levels and over fixed periods. These may vary by season.
CPP (critical peak pricing)	Prices increase by a known amount during specified system operating or market conditions. This applies during a narrowly defined period and is usually applied only during a limited number of days in the year.
TOU-CPP (time of use plus critical peak pricing)	Critical peak pricing overlaid onto time of use pricing. TOU-CPP therefore has two pricing components – daily time of use pricing, and occasional critical peak pricing applied during critical system events.
VPP (variable peak pricing)	Similar to time of use, but the peak period price varies daily based on system and/or market conditions rather than being fixed.
dTOU (dynamic time of use)	Prices vary between fixed price levels, but the timing of different prices is not fixed.
RTP (real time pricing)	Price can differ on a daily basis and change each hour of the day (or more frequently) based on system or market conditions.
Incentive based schemes	Description

Price based schemes	Description
CPR (critical peak rebate)	Similar to CPP, but customers are provided with an incentive for reducing usage during critical hours below a baseline level of consumption.
DLC (direct load control)	Customers are provided with an incentive for allowing an external party to directly change the electricity consumption of certain appliances. Customers can usually override control although they may lose some incentive. DLC may also be combined with time varying pricing.

Table 1: Types of pricing and other economic incentives discussed in this paper (Parrish, Gross and Heptonstall, 2019)

More specialised demand response products and services were also found in the demand response literature. In *local supply following,* different demand response products and services aim to shift demand to increase the use of renewable electricity generated locally (Carmichael *et al.*, 2014; Kobus *et al.*, 2015; Swinson, Hamer and Humphries, 2015; EcoGrid EU, 2016; Lebosse, 2016). *Peer-to-peer trading* aims to increase the use of embedded generation such as rooftop PV by directly trading surplus generation with other users locally (Moreno, 2013; Wiekens, van Grootel and Steinmeijer, 2014) . More specialised forms of automation include *smart appliances* such as washing machines, dishwashers, and tumble driers that automatically run at the optimum time, within the time slot set by users, to support more dynamic forms of demand response (Chassin and Kiesling, 2008; Belmans *et al.*, 2014; Wiekens, van Grootel and Steinmeijer, 2014; Kobus *et al.*, 2015). *Smart charging for electric vehicles* varies from simple timers to delay charging until night time

(Farhar *et al.*, 2016; Friis and Haunstrup Christensen, 2016), to more sophisticated technology to autonomously monitor low voltage distribution networks and dynamically curtail charging during times of high network load (EA Technology and Southern Electric Power Distribution, 2016). Battery storage could facilitate demand response by storing surplus renewable generation, supplying electricity to users during peak times to reduce peak demand the use of peak electricity, and direct control of battery charge and discharge could help to manage distribution network constraints (Western Power Distribution, 2016).

3. Research design and approach: A systematic review

The methodology used to identify the body of evidence discussed in this paper draws from previous methodological contributions offered by (Sorrell, 2007; Spiers, Gross and Heptonstall, 2015). This approach can be termed a systematic review. Systematic reviews of the literature, inclusive of academic literature and the “grey” or policy literature, aim to identify a comprehensive (though not exhaustive) selection of reports detailing factors influencing residential user engagement with different forms of demand response.

The authors began their review by searching the academic literature for studies on DR published between 1990 and 2016, using ScienceDirect. The authors searched for the terms (pilot OR trial OR programme OR program OR survey OR "focus group") AND TAK("demand response" OR "demand side response" OR "direct load control" OR "time varying pric*" OR "dynamic pric*" OR "real time pric*" OR "time-of-use") AND (residential OR domestic OR “SME”OR commercial OR business) AND electricity. A resulting corpus of 960 initial results was collected. Few results on small or medium businesses were identified, and only findings on residential demand response are presented in this paper.

Because much literature on demand response consists of policy reports rather than peer-reviewed literature, the authors complemented their academic search with that of the grey literature. Grey literature searches were focussed on sources that were identified through rapid evidence assessment and yielded the most useful information for Parrish, Gross and Heptonstall, (2019) and BEIS (2017). Table 2 gives details of these searches, which resulted in an additional corpus of 296 studies.

Grey literature source	**Search strategy**	**Number of results**
EC Europa inventory of European Smart Grid Projects	Initially reviewed all projects identified as Demonstration and Deployment (rather than Research and Development) AND identified as belonging to the category "Smart Customer and Smart Home".	117
US Department of Energy Smart Grid Investment Grant Consumer Behaviour Studies	Initially reviewed all Consumer Behaviour Study Program Reports.	14
US Electric Power Research Institute (EPRI)	Searched the term 'demand response' within two research programmes identified by EPRI: 1) "Energy Efficiency and Demand Response"	1) 59 2) 56

	2) "Understanding Electric Utility Customers"	
IEA Demand Side Management Energy Efficiency Technology Collaboration Program	Initially reviewed all completed tasks and associated publications.	50

Table 2: Grey literature search strategy

To filter this data, we relied on a screening process. Documents were excluded first based on their title/abstracts, and further excluded based on the full text where necessary, if they did not meet the following inclusion criteria:

- Geographical: Europe, North America, Australia and New Zealand, also Japan
- Sector: residential
- Evidence type: including some form of empirical evidence rather than theory alone
- Access: publications in English, available for free (or where the project team have journal database access)
- Any type of time varying pricing aiming to change electricity use at specific times, with or without additional information or automation (static time-of-use, dynamic

time-of-use, critical peak pricing, variable peak pricing, day ahead real time pricing, real time real time pricing)

- Direct load control or automation (e.g. via smart appliances) aiming to change electricity use at specific times
- Rebates aiming to change electricity use at specific times (critical peak rebate)
- Information (alone) aiming to change electricity use at specific times
- Include all of the above acting over specific local areas
- Include all of the above using battery storage, PV etc. to facilitate demand response

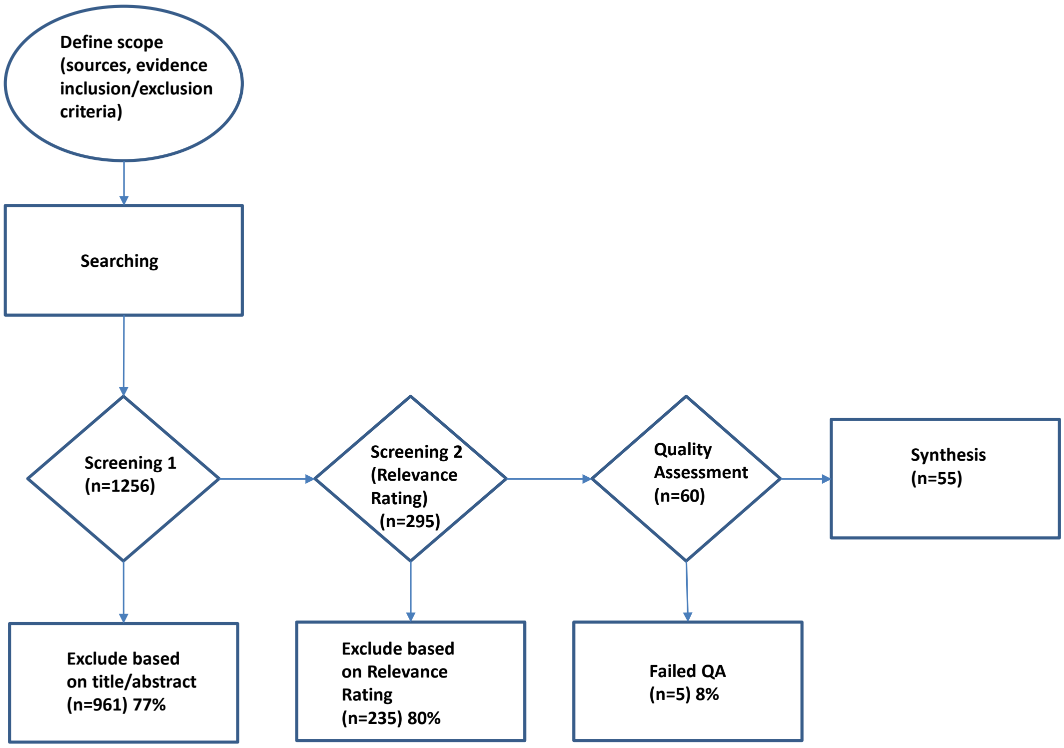

Fig. 3: Systematic Review Process Flowchart

This screening process, represented in Fig. 3, identified a total of 55 studies across the academic and grey literature. These covered a range of geographic locations, evidence types (trials, programmes, and stand-alone surveys) and forms of demand response. The distribution of evidence across these categories is summarised in Table 3. Trials and surveys represent the majority of the evidence base.

In this classification 'programmes' indicates residential demand response that has been implemented with the intention of providing services to a real electricity system, while 'trials' indicates the implementation of interventions such as time varying pricing, enabling technologies, and information provision for research purposes. 'Surveys' refers to surveys, focus groups or interviews that were conducted with people not taking part in a trial or programme of demand response (although such methods can also be used as part of research on consumer engagement with trials and programmes). A limitation of such stand-alone surveys, focus groups and interviews is that they capture data from consumers who may have no direct experience of demand response. On the other hand, many trials and programmes involve a self-selected group of participants because they recruit on an opt-in basis (voluntary recruitment). Therefore, while trials and programmes can provide evidence on consumers' actual behaviour when enrolled in demand response, surveys, focus groups and interviews can offer some insight into the attitudes of the general population. This review therefore includes findings from both categories of evidence.

Following our screening of the literature, the full body of evidence across the academic and grey literature was reviewed to identify findings on factors affecting residential user engagement with demand response. The impact of different forms of time varying pricing; information provision; and/or enabling technologies including automation, direct load control and in-home feedback on electricity price and/or use, were reviewed quantitatively in Parrish, Gross and Heptonstall (2019). To build on this work we focussed on identifying qualitative motivations, barriers or enablers for consumer engagement with residential demand response. Because the literature we reviewed was diverse in terms of the form of residential demand response examined, the study context and design, and the perspectives that informed its analysis, we have not attempted to quantify the frequency of specific findings, but instead we have categorised findings inductively across studies to allow themes to emerge.

The next three sections thematically present the factors influencing user engagement with demand response identified from the evidence base represented in Table

3. The first section discusses residential consumer motivations to enrol in demand response, and, to a lesser extent, to change demand patterns following enrolment. The next section discusses the themes that could be considered as enablers or barriers that are associated with an increase or decrease in residential consumer enrolment and/or response: familiarity and trust; perceived risk and perceived control; and complexity and effort. The final section discusses the influence of user characteristics and user routines.

Location	Evidence type	No. studies (mean no. participants)	No. studies by demand response products and services						
			sTOU	CPP	CPR	dTOU/RTP	In-home	Direct load	Automatio
UK	Trial	7 (505)	4	0	0	1	3	2	2
	Programme	0	0	0	0	0	0	0	0
	Survey	2 (1017)	2	0	1	1	0	1	2
Europe	Trial	9 (923)	4	1	0	5	1	1	2
	Programme	1 (no data on participant no.)	1	0	0	0	0	0	0
	Survey	4 (666)	1	0	0	2	0	2	3
North America	Trial	18 (7823)	11	10	3	3	8	0	7
	Programme	2 (no data on participant no.)	0	0	0	0	0	2	0
	Survey	6 (1599)	2	1	0	0	0	1	1
Australia & NZ	Trial	3 (142)	2	2	0	0	0	1	1

	Programme	1 (no data on participant no.)	0	0	0	0	0	1	0
	Survey	1 (53)	1	0	0	0	1	1	0
Totals			28	14	4	12	13	13	19
Reviews, meta-analysis and policy-analyses		5 studies							

Table 3: Categorisation of literature search results. Note that numbers do not sum across rows because a single trial, programme or survey may have included more than one type of intervention.

4. Results: motivations, barriers and enablers for residential demand response

This section presents the detailed findings of our systematic literature review to address the question: what are the key factors affecting residential user engagement with demand response? The first section describes residential consumer *motivations* for engagement with demand response. The second section describes themes emerging from the literature reviewed that could be considered as *enablers* or *barriers* for engagement with demand response: familiarity and trust; perceived risk and perceived control; and complexity and effort. The final section summarises findings on how *user characteristics* and *user routines* might influence engagement with demand response. These summary themes are carried forwards to inform the discussion in Section 5.

4.1 Results: Consumer motivations for demand response

This section considers why residential users might chose to enrol in demand response, and why they might chose to respond following enrolment.

The review identified a wide range of motivations for residential consumers to participate in demand response. Financial and environmental benefits were the most common motivations identified, and of these, financial benefits were typically given the highest importance (AECOM, 2011; Allcott, 2011; Dütschke and Paetz, 2013; Carmichael *et al.*, 2014; Torstensson and Wallin, 2014; US DOE, 2016). More specifically, some users state that bill reductions are more appealing than rewards or other financial incentives (Buchanan et al., 2016), although there may be little difference in actual enrolment rates for critical peak pricing and critical peak rebates (US DOE, 2016).

Only two trials reported environmental and other social benefits as more important, (Bradley, Coke and Leach, 2016; EcoGrid EU, 2016), although other studies found both were important, or did not compare them (Shipman, Gillott and Naghiyev, 2013; Hall, Jeanneret and Rai, 2016; Lebosse, 2016; Western Power Distribution, 2016). However, the potential environmental benefits of participating in demand response may not be obvious to users, for example, because total electricity use will not necessarily decrease as a result (Hall, Jeanneret and Rai, 2016).

A wide range of other motivations for enrolment were identified. Expected household-level benefits included free or reduced cost technology (Bird, 2015; Bradley, Coke and Leach, 2016), increased control over energy use and bills including through access to additional information (AECOM, 2011; Hall, Jeanneret and Rai, 2016; Western Power Distribution, 2016), and thinking participation in demand response might be fun or interesting (Strengers, 2010; Dütschke and Paetz, 2013). More social motivations included pride discussing participation with neighbours or being encouraged by children to be more environmentally friendly (Western Power Distribution, 2016), or helping to increase electricity system reliability (Bird, 2015; Lebosse, 2016). If demand response has a local focus this can act as an additional motivation (Carmichael et al., 2014; EcoGrid EU, 2016; Lebosse, 2016).

There is some evidence that after enrolling users continue to weigh up the potential financial savings against effort, time, convenience and comfort when deciding whether to change their electricity use (Bartusch et al., 2011; Bradley, Coke and Leach, 2016; EcoGrid EU, 2016; Friis and Haunstrup Christensen, 2016). Participants might also enjoy the challenge of responding to dynamic pricing and treat it like a game or project (Carmichael et al., 2014).

4.2. Results: Enablers and Barriers facing Demand Response

Our systematic review identified not only consumer motivations, but also a collection of enablers and barriers facing demand response. We have placed these into the categories of familiarity and trust, perceived risk and perceived control, and complexity and effort.

4.2.1 Familiarity and trust

Mistrust can arise before or after enrolment, and is often linked either to technology or technical issues or to a lack of clarity around what demand response involves and who it benefits. Concerns around privacy and autonomy connected to direct load control, and consumers' ideas of why energy companies pursue demand response can contribute to mistrust (AECOM, 2011; Bartusch et al., 2011; Wiekens, van Grootel and Steinmeijer, 2014; Lopes et al., 2016). Unfamiliarity can be linked with mistrust, for example unfamiliarity with the concept of demand response can contribute to mistrust of energy company motivations (AECOM, 2011). However, familiarity can have either positive or negative effects. Hall et al. (2016) linked the higher stated acceptance of time-of use tariffs to their availability in a local area, but found that awareness of public concerns about smart meter deployment caused users to be concerned about this enabling technology.

Trust may be promoted by measures that enhance transparency around demand response in general and, where relevant, direct load control in particular. Such measures include providing information on demand response from independent sources (Hall, Jeanneret and Rai, 2016), communicating how different parties such as users and energy companies benefit from demand response (Buchanan *et al.*, 2016; Lebosse, 2016), and notifying users of any direct load control actions taken (Lopes *et al.*, 2016). More generally, recruitment can be supported by the involvement of trusted actors (Bird, 2015; Western Power Distribution, 2016) including neighbours (EA Technology and Southern Electric Power Distribution, 2016).

Trust may be eroded following enrolment in demand response, and may then be hard to rebuild (Wiekens, van Grootel and Steinmeijer, 2014). Loss of trust may arise from installation delays (Western Power Distribution, 2016), technical issues (Wiekens, van Grootel and Steinmeijer, 2014), or opacity of dynamic pricing or automation schedules (Carmichael *et al.*, 2014; Wiekens, van Grootel and Steinmeijer, 2014). In addition, engagement with forms of demand response that involve community action, such as peer-to-peer trading, may be impacted if users do not trust the behaviour of other community members (Wiekens, van Grootel and Steinmeijer, 2014).

Similarly to at the enrolment stage, trust after enrolment may be promoted by increasing transparency and addressing technical issues. Engagement may be promoted by honesty and accountability about delays and technical issues (EcoGrid EU, 2016; Western Power Distribution, 2016), as well as addressing customer's questions and issues, anticipating common issues and preventing them before they escalate, and setting realistic expectations about participation, performance of technology, and potential bill savings (US DOE, 2016).

4.2.2 Perceived risk and perceived control

Perceived risk may be associated with different features of time varying pricing or rebates for demand response. Technologies that enable responses to time varying pricing may help to address the financial risk of time varying pricing, but can themselves be perceived as risky due to loss of control.

Higher price levels and less predictable pricing may increase perceived risk associated with time varying pricing. For example, perceived risk or complexity can deter some consumers from enrolling in real-time pricing (Allcott, 2011), while participants in one trial of dynamic time-of-use pricing said they would be more likely to sign up again if price changes were more predictable (Carmichael *et al.*, 2014). Some users prefer smaller high:low price ratios or a cap on price (Dütschke and Paetz, 2013), and others prefer time-of-use pricing to critical peak pricing perhaps due to the much higher price ratios associated with the latter (Buryk *et al.*, 2015).

Unlike time varying pricing, rebates that incentivise demand reduction carry no financial risk for participants, but we found mixed evidence on how this could influence enrolment. Users may state a preference for financial rebates rather than time varying pricing due to the absence of risk associated with the former (Bradley, Coke and Leach, 2016), and the use of rewards rather than financial penalties may facilitate recruitment (Lebosse 2016). However, a series of trials in the US found little difference in actual enrolment rates for critical peak pricing and critical peak rebates (US DOE, 2016). These trials did identify that critical peak rebates resulted in smaller and less consistent responses, but higher retention rates compared to critical peak pricing. Both effects were suggested to arise from the financial risk attached to critical peak pricing (US DOE, 2016).

Automation can enable responses to time varying pricing, and has been associated with higher stated acceptance of dynamic time-of-use pricing (Fell *et al.*, 2015). On the other hand, users might be concerned about loss of control associated with automation or direct load control (Hall, Jeanneret and Rai, 2016; Lopes *et al.*, 2016). Enrolment could be encouraged by features of direct load control or automation that increase users' perceptions of control. Such approaches include providing choice about how and when automation takes place; specific agreements on allowed control including limited duration; adequate notification of control; and the option to override (Buchanan *et al.*, 2016; Hall, Jeanneret and Rai, 2016; Lopes *et al.*, 2016). Users may also prefer automation over direct load control because it is perceived as allowing them to retain greater control (Wiekens, van Grootel and Steinmeijer, 2014; US DOE, 2016). However, some users may accept direct load control without override: the appliance standards set for air conditioners in New South Wales do not allow users to override the external control of their air conditioning, but attrition from the programme has been low, and reported satisfaction high (Swinson, Hamer and Humphries, 2015).

Concerns about direct load control or automation may increase or decrease following experience of these interventions. In a series of trials in the US, pre-trial market research indicated that users strongly preferred to programme thermostats themselves as they were reluctant to allow direct load control. However, experiences during the trial suggested that most users relaxed these concerns after gaining familiarity with the programmable thermostats and allowed direct load control by their utility (US DOE, 2016). Similarly to at enrolment, user engagement while experiencing automation or direct load control can be influenced by features that affect users' perceived control. In one trial participants given more control options felt more positive about direct load control of their heating, although they did not override control any more frequently than other groups (EcoGrid EU, 2016). Meanwhile, participant enthusiasm for smart appliances fell over the course of another trial, in part due to a perceived loss of control associated with a lack of feedback on the start and end times of automated smart appliances (Belmans *et al.*, 2014).

4.2.3 Complexity and effort

The level of complexity and effort associated with demand response can affect consumer engagement before and after enrolment. This may be linked to the predictability of pricing schedules, and the effort of responding can be reduced by enabling technologies, but the evidence on neither of these factors is straightforward.

Considering demand shifting in general terms, some users expect changing demand patterns would be difficult or undesirable due to inconvenience and impact on daily routines (Buryk *et al.*, 2015; Bradley, Coke and Leach, 2016; Lopes *et al.*, 2016). However, others expect changing demand patterns to be easy (Buryk *et al.*, 2015; Fell *et al.*, 2015; Lopes *et al.*, 2016). Some studies have highlighted the importance of how the effort consumers expect compares to the benefits they anticipate from participation (Allcott, 2011; Lopes *et al.*, 2016).

The complexity and effort involved in responding to time varying pricing may be linked to less predictable pricing schedules. For example, two trials of real time pricing reported very limited manual demand shifting because users found it difficult to change their use of appliances in line with continually changing price signals (Belmans *et al.*, 2014; Friis and Haunstrup Christensen, 2016). Similarly, some users report finding it harder to change demand on specific days rather than following a daily pattern (Lebosse, 2016). Even routine responses to static time-of-use pricing may be perceived as too much effort by some users (Farhar *et al.*, 2016). However, the evidence on this is mixed: in one trial of dynamic time-of-use pricing, 79% of respondents in the post-trial survey said they did not find the tariff too complex, 60% agreed it was easy to take advantage of low rates, and 50% agreed it was easy to avoid high rates (Carmichael *et al.*, 2014).

Automation or direct load control can reduce the complexity and/or effort involved in responding to time varying pricing (Belmans *et al.*, 2014; Wiekens, van Grootel and Steinmeijer, 2014; Farhar *et al.*, 2016; Friis and Haunstrup Christensen, 2016). These enabling technologies may be linked with perceived ease of use (Fell et al. 2015), and some users who are away from home during the day may choose them to increase response (Lebosse, 2016). However, making use of automation or accessing additional information provided by enabling technologies can itself be perceived as excessively complex or difficult (AECOM, 2011; Belmans *et al.*, 2014; Carmichael *et al.*, 2014; Farhar *et al.*, 2016). Similarly, the requirement to install new technologies can act as a barrier to recruitment (AECOM, 2011). This may be due to technology cost (Belmans *et al.*, 2014), space requirements (Bird, 2015), and the disruption associated with installations (Bird, 2015; Hall, Jeanneret and Rai, 2016). Technology installation can be a critical part of users' experience of demand response (Bird, 2015).

4.3. Results: User routines and characteristics

The previous results sections discussed the role of user motivations, and barriers and enabling factors in the uptake and level of demand response. Many of the studies reviewed also explored links between levels of engagement with demand response and various consumer characteristics, and/or the interaction between demand response and user routines.

4.3.1 User characteristics

Identifying more flexible groups of users could be helpful to better assess demand response potential, and inform users of whether they are likely to benefit from participating in demand response. Studies reviewed identified a number of approaches that could potentially be used to indicate higher or lower flexibility by users or households, which can be broadly categorised as socio-demographics; access to technology including the ability to make use of the range of available technologies; and the presence of dependents in households and time spent at home.

Some studies considered how user engagement varies with socio-demographic characteristics such as income and household size. Response was higher by households with higher income in the California SPP trial (Faruqui and George, 2005), and by homeowners in the UK CLNR trial (Bird, 2015). Evidence related to household size and composition is somewhat mixed. Smaller households gave larger average responses in the California SPP and UK EDRP (AECOM, 2011), but the opposite effect was identified by Thorsnes, Williams and Lawson (2012) and in the UK LCL trial (Carmichael *et al.*, 2014). Overall, the UK LCL trial found only weak correlations between household characteristics and demand response (Carmichael *et al.*, 2014). The CLNR trial suggested socio-demographic groups may not be most appropriate way to identify more flexible customer segments, who could instead be identified by "socio-technical" groups (e.g. households with more appliances) or "flexibility capital" (e.g. shift workers) (Bird, 2015).

Access to broadband and the specifications of existing appliances may restrict enrolment in some types of demand response (Bird, 2015; Lebosse, 2016; Western Power Distribution, 2016). Flexibility may be increased by access to and ability to use enabling technologies such as appliance timers (Carmichael *et al.*, 2014), better insulated buildings and access to and/or knowledge of alternative technologies such as fireplaces for heating (Carmichael *et al.*, 2014; Lebosse, 2016) or ways to keep cool without air conditioning (Strengers, 2010). Conversely, response may be inhibited by lack of awareness or difficulty using enabling technologies (Carmichael *et al.*, 2014; Western Power Distribution, 2016), misunderstanding the ways in which they are being asked to change their electricity demand patterns (Shipman, Gillott and Naghiyev, 2013; Lebosse, 2016), and incorrectly estimating the energy used by different appliances and the impact of changing the times that they are used (Wiekens, van Grootel and Steinmeijer, 2014).

Several studies identified time outside the home as a barrier to shifting demand, and spending more time in the home, or flexible working hours, as an enabler of response (Thorsnes, Williams and Lawson, 2012; Dütschke and Paetz, 2013; Torriti, 2013; Carmichael *et al.*, 2014; Strengers and Maller, 2014; Bradley, Coke and Leach, 2016; EcoGrid EU, 2016; Friis and Haunstrup Christensen, 2016; Lebosse, 2016). The UK CLNR found that households without dependents were more likely to respond to time-of-use pricing (Bird, 2015). Similarly, Friis and Haunstrup Christensen (2016) reported that families with small children tended to find shifting wet goods more stressful, although some reported finding it easy because they were already used to a high degree of planning. Overall this suggests that the presence of children or other dependents could make demand shifting more difficult.

4.3.2 User routines

Some studies explored how the match or mismatch between the requirements of demand response and existing user routines influenced flexibility. While some patterns can be identified, there is heterogeneity in the extent to which users can be flexible in their routines and activities in the home.

At the appliance level, 'non-time critical' wet goods (washing machines, dishwashers and tumble driers) are often the appliances most involved in manual demand shifting (Carmichael *et al.*, 2014; Wiekens, van Grootel and Steinmeijer, 2014; Lebosse, 2016). More generally, the UK LCL trial found that the appliances participants identified as most flexible were those for which they had the least fixed routines (Carmichael *et al.*, 2014). However, some users have various concerns about shifting the use of wet goods, including noise, safety, the quality of laundry (Belmans *et al.*, 2014; Carmichael *et al.*, 2014; Friis and Haunstrup Christensen, 2016; Lebosse, 2016) convenience (Carmichael *et al.*, 2014; EcoGrid EU, 2016), unwillingness to lose quality time in the home (Bartusch *et al.*, 2011; Friis and Haunstrup Christensen, 2016) and fixed roles for certain household members (Carmichael *et* *al.*, 2014). Similarly, comfort and convenience could influence users to override direct load control of water heating (Belmans *et al.*, 2014) or space heating or cooling.

Demand shifting could be enabled if it can involve behaviours that are less disruptive to existing routines. Dishwashers may provide greater flexibility than other wet goods because users more frequently programme them in the evening (Belmans *et al.*, 2014). Users may be more prepared to run dishwashers than washing machines overnight because it is less disruptive to existing family routines to unload clean dishes in the kitchen in the morning than hang laundry (Friis and Haunstrup Christensen, 2016). Similarly, night-time charging of electric vehicles can become part of the routine of locking up for the night (Friis and Haunstrup Christensen, 2016). In other cases, direct load control was implemented in a way that simply had little impact on participants, for example relatively short duration curtailments of heating, taking differing insulation levels into account (Lebosse, 2016).

On the other hand, some groups of users are apparently willing and able to be more flexible in their routines in order to respond. For example, some users left the house to avoid electricity use at certain times (Strengers, 2010; Carmichael *et al.*, 2014), changed which household member used appliances (Carmichael *et al.*, 2014), or created a fun family occasion out of using less electricity (Strengers, 2010; Western Power Distribution, 2016). One study reported consumers who treated responding to dynamic pricing as a game or a motivator to complete household chores (Carmichael *et al.*, 2014). Some studies report users changing the use of appliances typically considered inflexible, such as cooking and lighting (Carmichael *et al.*, 2014; Lebosse, 2016). Different demand response participants may simply experience different levels of disruption to their daily lives and routines (Bradley, Coke and Leach, 2016).

5. Discussion: Implications for residential demand response

The previous sections report findings on factors influencing user engagement with demand response. They identify motivations, barriers and enablers for residential user engagement with demand response, as well as ways in which users' routines and characteristics may influence engagement. This section discusses the implications of these findings for delivering demand response, by relating them to user engagement with different demand response types and approaches to rolling out demand response. It ends with suggestions for further work.

5.1 Features of demand response

There is a wide variety of residential demand response types, as indicated in Section 2. However, in general residential demand response types vary according to whether they involve *time varying pricing*, *rebates*, or a *payment* for accepting direct load control; the *spread between high and low pricing*; the *predictability* of pricing or other schedules; and whether *enabling technologies* such as automation or direct load control are involved. This sub-section discusses how the various factors influencing user engagement described in Section 4 relate to these generic features of demand response, considering financial incentives, pricing and other schedules, and enabling technologies.

Financial incentives: This review identified a range of different motivations for enrolment, but the most common related to financial and environmental benefits. Financial benefits were most often found to have the highest importance in studies that assessed the relative importance of these two types of motivations. Some studies reported that users continue to consider the potential for financial savings as well as the impact on their daily lives when deciding whether to change electricity demand patterns following enrolment. This suggests that adequate financial incentives may be necessary to attract participants to residential demand response programmes. This could involve sufficiently large rebates, price spreads, or payments for direct load control. However, some studies indicate that high peak prices could increase perceptions of risk and discourage enrolment. Rebates carry no financial risk, but there is mixed evidence on whether they encourage higher recruitment than the equivalent dynamic pricing.

Pricing and other schedules: Some residential users engage with more dynamic or unpredictable forms of time varying pricing, but in general, less predictable pricing schedules may increase perceptions of risk, increase the complexity and effort associated with response, and create mistrust. The studies reviewed indicate that trust may be supported by transparent pricing, while enabling technologies may reduce perceived risk and complexity/effort. However, other studies indicate that the impact of demand response on users' routines also influences complexity and effort, and that direct load control is likely to be more acceptable if it has lower impacts on comfort and convenience. This suggests that enabling technologies may be less able to reduce complexity and effort if they produce responses that conflict with user routines.

Conversely, more predictable pricing could enable the formation of new routines supporting response. The review revealed heterogeneity in both users' routines and their degree of flexibility. However, the evidence reviewed suggests that at least some users find demand response easier if their responses can become routine, and that this may be favoured by more predictable forms of time varying pricing. Overall the findings of this review suggest that less dynamic and more predictable forms of demand response may increase residential user engagement. The literature indicates that an exception may be cases where demand response is automated and involves changes to demand, such as short duration curtailment of heating, that do not impact on user routines and activities in the home.

Enabling technologies: Technologies such as automation or direct load control are designed to reduce the complexity and effort of demand response by facilitating demand shifting without the need for manual behaviour change. Our review found evidence that direct load control and automation can reduce perceived complexity, effort, and risk associated with residential demand response, but can also themselves introduce a series of barriers to engagement with demand response. Firstly, installing and/or using some enabling technologies can itself be complex and/or difficult for some consumers. Secondly, although enabling technologies could reduce the risk of paying more by facilitating responses to higher prices, consumers may perceive a risk of losing control because of these technologies, although automation may be seen as offering greater user control than direct load control. Finally, expectations or experiences of enabling technologies may be linked to a loss of trust. Concerns about loss of autonomy and control may reduce trust at enrolment, and technical issues and opaque scheduling of automation or direct load control may reduce trust over time.

5.2 Approaches to delivering demand response

There are clearly trade-offs in the influence of different features of demand response on user engagement. Different approaches to delivering demand response can also influence engagement, and could help to address these trade-offs.

For example, while automation and direct load control can support engagement with residential demand response, these technologies may also introduce barriers to engagement. The ways in which automation and direct load control are delivered can reduce these barriers. For example, the reviewed literature suggests that perceptions of risk associated with direct load control may be reduced by delivering it in a way that increases perceived control, such as limiting possible direct load control actions, notifying users about control actions and providing more options for users to shape control including the ability to override.

More generally, the review revealed trust as an important factor in residential user engagement with demand response. Trust can also be influenced by how demand response is delivered. The literature reviewed indicates that trust during recruitment could be encouraged by providing transparent information on how different parties benefit from demand response, and/or by involving trusted actors in recruitment. After enrolment, trust could be encouraged by follow up engagement including setting realistic expectations about demand response, communicating effectively when customers have questions or problems, dealing with issues before they escalate and clear communication and accountability about issues that do arise.

Understanding variation in user engagement with demand response could help to protect users by informing them of whether they are likely to benefit or lose out from participating in residential demand response. However, this review did not identify clear links between different user segments and levels of engagement, which suggests that advice to consumers may need to take the form of more general information allowing more informed decisions about their participation. In particular, socio-demographic data is not always useful in predicting the potential for demand response. Metrics such as household size and income perhaps indirectly indicate factors such as the number of appliances owned, and it seems likely that such links and the ways in which they influence flexibility vary between different contexts. More informed participation in demand response could be supported by approaches such as calculator tools that allow users to better assess whether they might pay more or less on different forms of time varying pricing, or bill guarantees to allow users to try time varying pricing for a limited period without the risk of paying more (US DOE, 2016). The reviewed literature indicates that availability and knowledge of enabling and alternative technologies, time spent at home, and the presence of dependents appear to be better able to explain differing levels of flexibility. This suggests that it may also be possible to increase demand flexibility by providing support to use enabling technologies, or alternative ways to achieve energy services.

A number of studies reviewed indicated that experience of demand response, either personally or also through its local reputation, can have positive or negative impacts on consumer engagement. One study also suggested that users' trust can be hard to rebuild once it has been eroded. The findings of this review could contribute to guide early efforts to deploy residential demand response more widely with the aim of avoiding early negative experiences that could hinder further engagement.

5.3 Suggestions for further work

The complexity of findings in terms of details of demand response design and implementation, context, and user heterogeneity make it difficult to draw unequivocal conclusions about the impact of these individual dimensions on user engagement. Better understanding which groups of users are more likely to engage with residential demand response could have benefits including more accurate assessment of demand response potential, and protecting users by better informing them of whether they are likely to benefit from different demand response products and services.

The findings of this review indicate that user engagement with demand response can change with experience. While there are long standing examples of residential demand response, many of the studies reviewed were conducted over relatively short time frames. The timing of a study or its emphasis on certain themes may also have influenced the findings of the studies reviewed. For example, if the organisers of demand response trials or programmes recruit participants by emphasising the financial benefits on offer to them, this may contribute to consumers placing greater importance on financial rather than, for example, environmental motivations for participation. Similarly, the technology involved in demand response may also change over time. Ongoing evaluations of early efforts to increase deployment would therefore be valuable.

6. Conclusions and policy implications

Demand response is increasingly attracting policy attention as a resource that could increase the flexibility of electricity systems and support energy system decarbonisation. There is evidence that at least some residential users engage with at least some forms of demand response, but considerable variation in user engagement could impact on demand response as resource to manage electricity systems (EPRI, 2011; Carmichael *et al.*, 2014; Parrish, Gross and Heptonstall, 2019). To contribute to understanding this variation, this paper identifies factors affecting residential consumer engagement with demand response.

The paper is based on the findings of a systematic review of academic and grey literature. This review identified a final sample of 55 relevant studies, covering a range of geographic locations, evidence types (trials, programmes, surveys or focus groups) and forms of demand response. From this review, a number of general features that could influence residential user engagement with demand response emerged. These features, and the possible policy implications for residential demand response, are summarised in the remainder of this section.

First, our study identifies a range of factors that influence residential user engagement with demand response. These include:

- **Financial and other motivations for enrolment and response:** Financial and environmental benefits were the most commonly identified motivations for enrolment, and where these were compared, financial benefits were generally found to have the highest importance. Over time users may continue to weigh financial benefits against the effort of responding.
- **Familiarity and trust:** Users may mistrust the perceived motivations of demand response organisers, and this can be exacerbated by unfamiliarity with demand response and the ways in which it can create cost savings. However, greater familiarity with demand response could have positive or negative effects on engagement, depending on experiences and reputation in the specific context. More specifically, concerns around privacy and autonomy associated with direct load control may reduce enrolment, while technical issues and opaque dynamic pricing schedules may erode trust over time.
- **Perceived risk and perceived control:** Enrolment may be discouraged by perceived risk and encouraged by perceived control by users. Direct load control, high price levels and less predictable pricing schedules may be associated with perceptions of risk and/or reduced control. The perceived risk of dynamic pricing may be reduced by

some form of enabling technology, and users may see automation as allowing greater control than direct load control. Experience could decrease concerns about direct load control, but concerns may also increase if users experience technical issues. The risk of higher electricity bills may encourage response but reduce enrolment over time.

- **Complexity and effort:** Users may weigh expected complexity and effort against expected benefits from demand response when deciding whether to enrol. Responses may be limited if more dynamic pricing increases the difficulty of changing demand patterns, but different users consider different levels of complexity and effort to be acceptable. Enabling technologies in the form of automation or direct load control may reduce the complexity and effort associated with responding.
- **Interaction with user routines and activities:** Demand response could be facilitated if it is less disruptive to existing routines. However, different groups of users appear to be experience different levels of disruption or be more or less willing or able to change their routines in order to respond.
- **User characteristics:** Evidence on the usefulness of socio-demographic data such as income and household size to predict flexibility is mixed. Potentially more flexible users may include those spending more time at home; households without dependents; and users with knowledge of and access to enabling technologies and/or alternative ways to obtain energy services.

The complexity of findings in terms of details of demand response design and implementation, context, and user heterogeneity make it difficult to draw unequivocal conclusions about these individual dimensions. Nonetheless, the findings of this review indicate how different features and approaches may influence engagement with residential demand response, and could contribute to guide early efforts to deploy residential demand response more widely.

Policies to encourage user engagement with residential demand response could be informed by relating factors that influence user engagement to the characteristics of different demand response products and services and approaches to deliver these. There are a wide variety of residential demand response products and services, but in general they vary according to three dimensions. Firstly, *financial incentives* may involve time varying pricing, rebates, or a payment for accepting direct load control, and the spread between high and low pricing may also vary. Secondly, pricing or other schedules may vary in terms of their *predictability.* Thirdly, *enabling technologies* such as automation or direct load control may or may not be involved. Table 4 summarises how these generic features interact with the factors influencing residential consumer engagement with demand response identified by this review. Overall, our findings suggest that sufficiently high financial incentives and more predictable forms of demand response would tend to support residential user engagement. Enabling technologies may also support engagement if they are implemented in ways that do not reduce trust and perceived control.

	Motivations	**Familiarity and trust**	**Perceived risk and control**	**Complexity and effort**	**User routines and characteristics**

Financial incentives	Financial incentives may need to be large enough to attract participants		High peak prices could increase perceptions of risk, but there is mixed evidence on whether (risk-free) rebates increase enrolment		
Predictability			Some residential users engage with more dynamic or unpredictable forms of time varying pricing, but in general, less predictable pricing schedules may increase perceptions of risk, increase the complexity and effort associated with response, and create mistrust.		More predictable pricing could enable the formation of new routines that support response.
Enabling		Technical issues, or opaque		Enabling technologies may reduce perceived risk and complexity/effort, but less so if responses conflict with user routines.	

	scheduling of automation or direct load control may reduce trust over time.	Perceived control may be increased by: automation rather than direct load control; limiting or allowing users to alter direct load control	

Table 4: How factors influencing residential user engagement relate to generic features of demand response (Authors' own)

In addition to these generic features, the ways in which demand response is delivered can also influence consumer engagement. Our research suggests that trust could be encouraged by providing transparent information on how different parties benefit from demand response, involving trusted actors in recruitment, and setting realistic expectations. Communicating effectively when customers have questions or problems, dealing with issues before they escalate, and clear communication and accountability about issues that do arise can help to maintain trust. If direct load control is implemented, users may perceive greater control if they are notified of which control actions take place. It may be possible to increase demand flexibility by providing support to use enabling technologies, or alternative ways to achieve energy services. Finally, although we did not identify clear findings on which consumer segments could benefit from demand response, general information, bill calculator tools or bill guarantees could help to inform and protect consumers.

Ultimately, the evidence suggests residential user engagement with demand response is complex. Financial motivations appear to be important in enrolment, but user engagement is also influenced by factors including familiarity and trust, perceived risk and perceived control, and complexity and effort. These can relate to characteristics of demand response products and services such as direct load control, other automation technologies, and more or less predictable pricing schedules. Furthermore, while demand response may be facilitated if it is less disruptive to existing routines, different users experience demand response differently, and user engagement can also depend on the details of how demand response is delivered. Further research could offer greater insight into this complexity but the findings of this review offer guidance to maximise potential and avoid risks associated with residential demand response's initial deployment.

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